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An algorithm for defining the onset and cessation of the flexion-relaxation phenomenon in the low back musculature

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ABSTRACT

The flexion-relaxation phenomenon (FRP) in the low back provides insights into the interplay between the active and passive tissues. Establishing a reliable algorithm for defining the lumbar angle at which the muscles deactivate and reactivate was the focus of the current paper. First, the EMG data were processed using six different smoothing techniques (no smoothing, moving average, moving standard deviation, Butterworth low pass filter at 0.5 Hz, 5 Hz, and 50 Hz) herein called the processed EMG (pEMG). The FRP points were then defined using four thresholds (pEMG less than 3% MVC, pEMG less than 5% MVC, pEMG less than 2 times FRP pEMG, and pEMG less than 3 times FRP pEMG). Finally, a duration requirement was tested (no duration requirement, pEMG data must maintain threshold requirement for 50 data points). Each combination of smoothing, threshold, and duration were applied through a computer program to each muscle for all trials and established an EMG-off and EMG-on angle for each muscle. These estimates were compared to the gold standard of expert-identified EMG-off and EMG-on angles and the root mean square error (RMSE) between this gold standard and the predictions of the algorithms served as the dependent variable. The results showed that the most important factor to produce low values of RMSE is to utilize a Butterworth low pass filter of 5 Hz or less and, if this is employed, there is no value to a duration requirement. The results also suggest that using the “3 times FRP pEMG” threshold technique may provide further improvements in these predictions.

1. Introduction

The flexion-relaxation phenomenon (FRP) has been explained as a synergistic load-sharing mechanism between active tissues (i.e., muscles) and passive viscoelastic tissues (e.g., ligaments, tendons, intervertebral discs, etc.) in the low back (Schultz et al., 1985). This myoelectric silence period often shows interesting alterations depending on the low back condition. The initiation and cessation of the EMG silence could be affected by the coordination of trunk and hip movement (Gupta, 2001), trunk velocity (Sarti et al., 2001), stretched passive tissues in low back (Solomonow et al., 2003a; Shin et al., 2009), low back muscle fatigue (Descarreaux et al., 2008), low back pain (Alschuler et al., 2009) and gender (Solomonow et al., 2003a). The results suggest that the FRP may be a worthwhile topic for discovering the underlying control mechanism and dysfunction in the low back. In those FRP studies, the ‘FRP initiation lumbar flexion angle (EMG-off)’ and ‘FRP cessation lumbar flexion angle (EMG-on)’ are the most common parameters employed to test hypotheses (Neblett et al., 2003). However, there has been no common agreement to define the EMG-off and -on angle of FRP when employing computer-based algorithm (Table 1).

Previous studies have employed a visual inspection method that is subjective and time-consuming (Dickey et al., 2003; Descarreaux et al., 2008; Gupta, 2001). A few studies attempted computer-based methods using various smoothing techniques and thresholds (Olson et al., 2004; Shin et al., 2009). The absolute-reference threshold using maximum voluntary contraction (MVC) is commonly employed (McGill and Kippers, 1994; Shin et al., 2009). The method usually determines a threshold such as 5% integrated EMG (IEMG) of MVC, and then uses the threshold for all experimental trials to find the EMG-off points. The method may increase objectivity of the analysis for EMG-off points, but the MVC trials can be potentially affected by the individual motivation and ability to perform the maximal exertions (e.g., low back patients). In other words, the absolute-reference threshold using MVC itself introduces variability (Mathiassen et al., 1995). Also, the absolute-reference is employed for all trials without modification, so it cannot sensitively interact with the characteristic of each trial such as changes in muscle activation pattern. A self-reference (i.e., within trial) method using EMG data from each experimental trial may address some

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Table 1
Summary of criteria to define onset and cessation of FRP.

Authors	Threshold	Signal processing	Method
McGill and Kippers (1994)	3% of MVC	Low pass filtered at 2 Hz using Butterworth filter	Reference-based
Gupta (2001)	Abrupt changes	N/A	Visual inspection
Sarti et al. (2001)	Abrupt changes	100 ms moving average	Visual inspection
Dickey et al. (2003)	1% of MVC	Low pass filter at 6 Hz; down-sampled to 20.5 Hz (smoothing)	Visual inspection
Solomonow et al. (2003a)	N/A	100 ms moving average	Visual inspection
Olson et al. (2004)	5% of peak EMG during extension	Low pass filtered at 0.5 Hz using Butterworth filter	Reference-based
Olson et al. (2006)	N/A	Low pass filtered at 10 Hz using Butterworth filter	Visual inspection
Descarreaux et al. (2008)	N/A	10–450 Hz bandpass Butterworth filter	Visual inspection
Shin et al. (2009)	3% of MVC	Low pass filtered at 3 Hz using Butterworth filter	Reference-based

of these concerns. The goal of this study was to examine computer-based algorithms for defining the lumbar flexion angles at which the myoelectric silence occurs during the trunk flexion motion (EMG-off) and the lumbar flexion angle at which the myoelectric activity reappears during the trunk extension motion (EMG-on).

2. Methods

2.1. Subjects

This study employed a sample of recordings of EMG activity captured for previously published FRP study involving eight male participants with average age 26.2 (SD 2.9) years, height 178.2 (SD 5.0) cm and total body mass 70.6 (SD 5.3) kg (Ning et al., 2011). All procedures in the study were reviewed and approved by the Institutional Review Board for the Use of Human Subjects in Research.

2.2. Data collection

Surface electromyography (Model: Bagnoli, Delsys Inc., Boston, MA) employing four bipolar surface EMG electrodes (Model DE 2.1 active, single differential electrodes) was placed bilaterally over the L4 paraspinals (2 cm lateral from L4 spinous process) and L3 paraspinals (4 cm lateral from L3 spinous process) (collected at 1024 Hz). The muscles were selected to investigate possible differences in the best algorithm for muscles with somewhat different functions.

Trunk kinematics data were collected using a magnetic field-based motion tracking system (Model: Motion Star (tethered model), Ascension Technology Corporation, Burlington, VT). Two sensors were secured to the skin over the T12 and S1 vertebrae and used to calculate lumbar flexion angle, defined as the difference between the T12 and S1 sensors in the sagittal plane (collected at 102.4 Hz). Data acquisition software (Motion Monitor Version 7.72, Innovative Sports Training, Chicago, IL) was used to collect and synchronize EMG and kinematics data. A lumbar dynamometer (Model: Kin/Com (hydraulic), Chattanooga Group, Inc., Chattanooga, TN) was used in conjunction with the asymmetric reference frame to provide static resistance and control of trunk flexion angle during the trunk muscle maximum voluntary contraction (MVC) exertions (Mirka and Marras, 1993).

Before the experimental trials, two MVCs in a 20° trunk flexion posture were collected, and used to calculate the 3% and 5% IEMGs of the MVCs (see Section 2.3). The subjects were then asked to perform five slow, controlled, sagittally symmetric trunk flexion–extension trials. In all conditions the pace of the motion was set as: 7 s to move from upright to full flexion; 6 s of maintaining full flexion posture (including an exhale); and another 7 s to move from full flexion to the upright posture. A metronome was used to assist the participants in maintaining the appropriate pace during the flexion–extension motion. An external trigger was used to indicate the timing of the full flexion posture, required in the data analysis process.

2.3. Computer-based FRP determination

A total of 160 EMG signals (eight subjects $\times$ five repetitions $\times$ four muscles (both right and left L3 and L4 paraspinals)) provided the data set on which we tested the effects of the 48 different combinations of the levels of the three independent variables: smoothing techniques (six levels), threshold metrics (four levels) and duration requirements (two levels) (Table 2). Prior to implementing the computer-based algorithms a basic EMG processing procedure was conducted. The EMG data from the four muscles were filtered using a low-pass filter of 500 Hz, a high-pass filter of 10 Hz and the signal was notch filtered at 60 Hz (power supply noise) and 102.4 Hz (motion tracking system) and their harmonics up to 500 Hz. Each of these filtered EMG signals were then processed using all 48 processing techniques and these techniques are described in more detail below.

First, the ‘smoothing’ techniques considered in this study were those that have been used in previous studies and graphical presentations of the six techniques are shown in Fig. 1. For five of the six techniques (all except moving standard deviation (SD) technique) the signals were first rectified. In the no-filter condition this was the end of the signal processing. In three of the smoothing conditions a fourth order, zero lag Butterworth low pass filter (dual pass) was applied on the rectified EMG signal (0.5, 5 and 50 Hz). The EMG data were filtered in the forward direction first, and the filtered sequence was then reversed and run back through the filter (dual pass). This method has been shown to provide precise zero phase distortion (Mitra, 2001). The last two smoothing conditions employed moving windows of size 256 data points where the window was centered about each sample to minimize possible phase distortion. The moving average (MAV) technique simply averaged the values in the window of the rectified data. The moving SDs (MSD) technique simply quantified the standard deviation of the values in the window of the unrectified data. The techniques created a series of averages or SDs of moving subsets of the full data set, and finally generated what we will call herein the processed EMG (pEMG) profile. Fig. 1 represents pEMGs of all six types of data smoothing techniques. Thus, for our analysis the five levels of the independent variable ‘smoothing’ are: “None”, “50 Hz”, “5 Hz”, “0.5 Hz”, “MAV”, and “MSD”.

Second, the ‘threshold’ was defined as the point at which the magnitude of pEMG signals met the predetermined values (i.e., thresholds). Two categories of threshold were used: absolute-reference threshold and self-reference threshold were tested. The absolute-reference threshold makes use of data collected during MVC exertions prior to the experimental trials. In the current study the two levels of absolute threshold were 3% and 5% MVC (i.e., 3% and 5% of the integrated EMG from the MVC exertions). These are called absolute because the threshold was defined once and then